Two-Dimensional Modeling to Evaluate Shallow Water Habitat Creation on the Main Stem of the Missouri River in Nebraska

Lynnette F. Schaper, P.E[1] and Paul M. Boyd[2]

[1]Hydraulic Engineer, CENWO-ED-HF, Sedimentation and Channel Stabilization Section. ph. (402) 221-7189 Lynnette.F.Schaper@nwo02.usace.army.mil
[2]Hydraulic Engineer, CENWO-ED-HF, Sedimentation and Channel Stabilization Section. ph. (402) 221-4592 Paul.M.Boyd@nwo02.usace.army.mil

Abstract

Two-dimensional modeling is being used as part of the Missouri River Bank Stabilization and Navigation, Fish and Wildlife Mitigation Project. The project goal is to evaluate the creation of shallow water habitat by the use of constructed structures along the channelized section of the Missouri River in Nebraska. The goal is to be accomplished through the creation of deposition regions in the structure vicinity. Two study sites, Boyer Bend and Hamburg Bend, on the main stem of the Missouri River, are currently being evaluated for the creation of shallow water habitat.

A model was build for each site using the Surface Water Modeling System (SMS) and simulated using RMA2 WES two-dimensional hydraulic model and SED2D WES to estimate sediment transport using the RMA2 WES solution. Currently, the Hamburg Bend model has been calibrated to the established HEC-RAS model of the Missouri River, and sediment transport analysis is underway. The Boyer Bend model has undergone significant refinement to achieve a stable solution. When both models have been refined to simulate the navigation season, geometry modifications will be implemented to evaluate multiple alternatives to create shallow water habitat.

The Missouri River Mitigation Project

The Missouri River Biological Opinion (MRBO) states that the Corps of Engineers (Corps) provide the primary operational management of the Missouri River and is therefore responsible under the Endangered Species Act to take actions within its authorities to conserve listed species (USFWS, November 2000). The Reasonable and Prudent Alternative (RPA) includes five parts applicable. These actions are as follows:

1) Flow Enhancement
2) Habitat Restoration/Creation/Acquisition
3) Unbalance System Regulation
4) Adaptive Management/Monitoring
5) Propagation/Augmentation

Of the five actions listed by the Fish and Wildlife Service (Service) the Habitat Restoration/Creation/ Acquisition is the one of concern here. Habitat Restoration/Creation/Acquisition applies to the formation of shallow water habitat and the purpose of the two-dimensional modeling presented in this paper. The Service has determined that a portion of the historic habitat base must be restored, enhanced, and conserved in riverine sections that will benefit the three species of concern, the least tern, the piping plover, and the pallid sturgeon. Habitat restoration goals are to create 20-30 acres of shallow water (<5 feet deep, < 2.5 feet/second velocity) per mile. In addition, similar variable goals by river segment for emergent interchannel sandbar habitat are also identified. The near term goals of the project are to reach 10% (2000 acres) of shallow-water habitat by year 2005 and 30% (5,870 acres) of shallow-water habitat by year 2010. Additional information on the RPA and the implementation objectives can be found in the MRBO Table 24.

The Corps has designed a plan (USACE, 2002) describing a process by which the Corps will modify the existing Missouri River Streambank Stabilization and Navigation Project (BSNP) in an attempt to meet the MRBO goal of 2000 acres by the year 2005. The objective of the shallow-water habitat development is to create the required habitat acreage, and develop the design tools necessary to continue habitat development into the future while maintaining the authorized project purposes. Goals of the habitat creation are to allow for more dynamic alluvial processes and increased depth/velocity distribution within the wider top width of the channel. The habitat parameters of depth and velocity are a function of discharge. In order to measure the effectiveness of the proposed project modification, an effective or design discharge much be defined. For the purposes of assessing habitat creation, it was decided to use the 50% exceedance discharge from the August flow duration curve(s) as the effective discharge. These data will be used to develop habitat duration availability curves at representative sites, as shown in Figure 1. By shifting the present curve to the right and upward on the graph, available acres can be added at the same percent time exceeded.

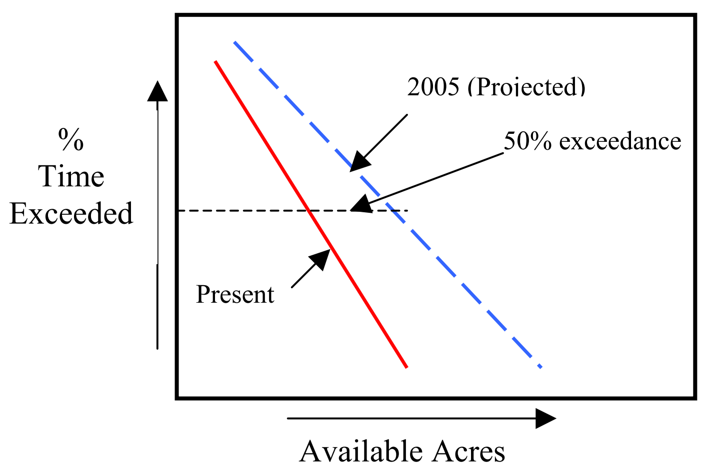

Figure 1. Conceptual Habitat Availability Curves.

Modeling purpose and attempts

The purpose of building the model is to monitor and evaluate the proposed Corps plan and apply the knowledge gained to the future long-range project. Two-dimensional modeling has been recommended based on previous modeling attempts and on the quality and type of data the two-dimensional model will provide.

Past mitigation projects had used the one-dimensional model HEC-6 (USACE, 1995). HEC-6 did not provide the fine-detailed modeling needed to evaluate depth diversity and velocity changes. The Iowa Institute of Hydraulic Research used a three-dimensional modeling on the Missouri River at Leavenworth Bend (Spasojevic et al., 2001). The three-dimensional model resulted in an inefficient method to model the River; as the model took longer than real time to run a set time frame.

A micro model (a.k.a. table top model) of Copeland Bend on the Missouri River modeled various widths to widen the channel (Davinroy et al., 1999). The results set thresholds of channel widths that the river could withstand and satisfy the goals of the MRBO. These results can be used in future modeling.

The choice to use the two-dimensional model SMS/RMA2/SED2D is driven by the need to predict a wide range of flows and being able to model velocities and depth across the width of the channel with more accuracy. The model is anticipated to be used as a benchmark in not only evaluating alternatives, but in monitoring performance over the project's life.

Two-Dimensional Modeling Solutions for the Missouri River Mitigation Project

RMA2 WES is a two-dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two dimensional flow fields. RMA2 WES computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed (Donnell, 1997). The solution of the RMA2 WES hydraulic model will be used as a platform to evaluate sediment transport with the SED2D WES model. The SED2D WES model uses a simplified version of the Ackers-White sediment transport equation with a single sediment size.

SED2D WES can be applied to clay or sand bed sediments where flow velocities can be considered two-dimensional in the horizontal plane (i.e., the speed and direction can be satisfactorily represented as a depth-averaged velocity). It is useful for both deposition and erosion studies and, to a limited extent, for stream width studies (Donnell, 2000).

To be able to efficiently manage data in and out of these models, the Surface-Water Modeling System (SMS) was used as a pre- and post-processor for the RMA2 WES and SED2D WES models.

By developing two-dimensional hydraulic and sediment models on selected stretches of the main channel of the Missouri River, it is hoped that new management alternatives with potential to increase shallow water habitat can be effectively investigated. The primary changes that will be evaluated include notching the existing dike tops, raising of and lowering of dike structures.

Mitigation Sites

Two models are currently under development. The Hamburg Bend model includes upper and lower Hamburg Bend immediately below Nebraska City, Nebraska, between river miles 550.0 and 556.3. Incorporating 54 dike structures, the model also includes an existing chute on the west side of the river, and a proposed chute on the east side. The basic model mesh for the Hamburg Bend model was developed under contract by WEST Consultants, San Diego, CA, during the fall of 2002 (WEST, 2003). Omaha District refined the mesh during the model development and calibration process. The developed model was roughly calibrated to water surface elevations at three flowrates. Flows of 28,000 (28k), 45,000 (45k), and 60,000 (60k) cfs were modeled. The 28k flow is slightly lower than the shallow water habitat criteria flow and the 60k flow is slightly less than bank full.

The Boyer Bend model was developed by the Omaha District. The Boyer Bend model mesh includes river miles 633.4 to 638.0. The area includes 21 existing dikes and the entrance of the Boyer River at approximately river mile 636. Due to the much smaller model size, more detailed mesh development was possible with the Boyer Bend mesh. Figure 2 shows the plan view of the two models developed.

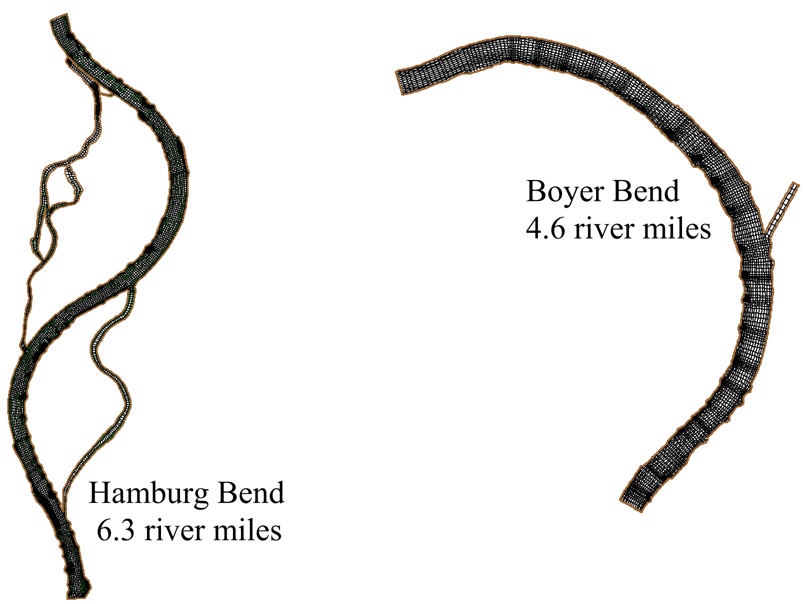

Figure 2. Model mesh plan views (not to scale)

Different methodologies were implemented in the creation of the two meshes. To produce high detail, the Boyer Bend model incorporated small elements with size transitions between elements kept to a minimum. Due to the size of the Hamburg Bend mesh, main channel elements were made considerably larger than in the Boyer

Bend mesh. This created large changes in element size transitioning from channel to dike, and reduced the element resolution in the dike fields. If the Boyer Bend element dimensions were used in developing the Hamburg Bend mesh, an extremely large mesh would be created, resulting in considerable processor time for analysis. Figure 3 shows a typical dike developed in the Hamburg Bend mesh. Figure 4 shows a typical dike built in the Boyer Bend mesh.

Initial testing and calibration with the Boyer Bend mesh indicates that mesh creation using the detailed dike modeling structure with smaller transitions may reduce stability problems caused by extreme changes in mesh geometry. The detailed dike construction style also greatly reduces the number of triangular elements in the mesh. In the Hamburg Bend mesh, close to 34 percent of the elements are triangular, as compared with 14 percent in the Boyer Bend mesh.

Hamburg Bend mesh refinement and calibration

Beginning with the Hamburg Bend provided by WEST Consultants, refinement of the Hamburg Bend mesh was performed in an effort to minimize mesh areas that may cause future problems and improving areas in the mesh to help meet project goals. Initially, mesh quality concerns were addressed, including ambiguous gradients, large changes in element size, and large interior angles. Secondly, in areas where instabilities were common, the mesh was refined and the elements made more uniform to increase model stability. Due to the large mesh size, refinement of all dike elements to the degree desired is not possible without exceeding a practical limit on total mesh size.

The delivered Hamburg Bend mesh included almost 9,000 elements. Following refinement it contains just less than 11,000 elements. To keep model process time within the reasonable limitations of current computer equipment, refinement of the mesh was only carried out where necessary to allow the model to converge to a stable solution.

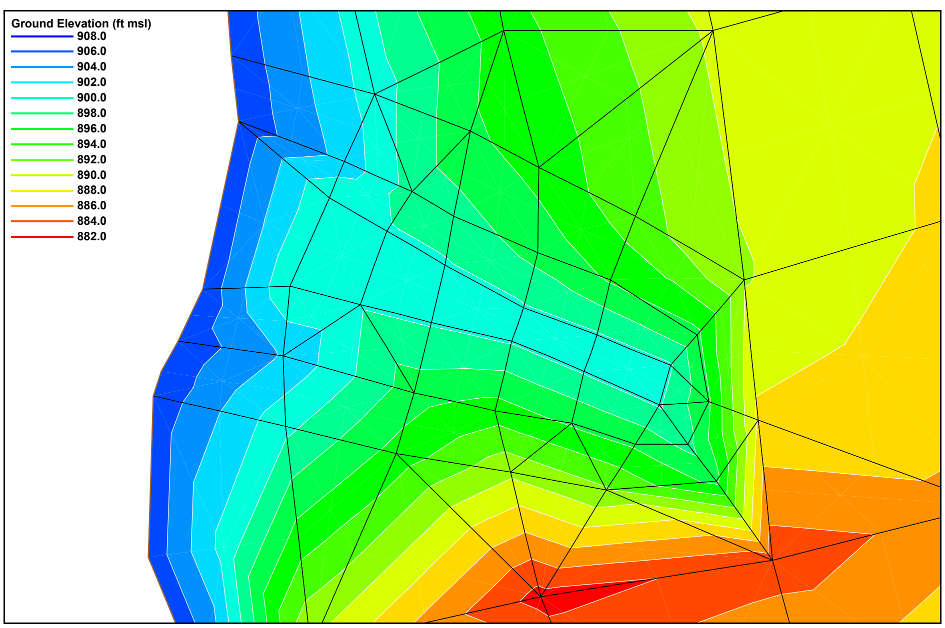

Figure 3. Unrefined dike in Hamburg Bend mesh

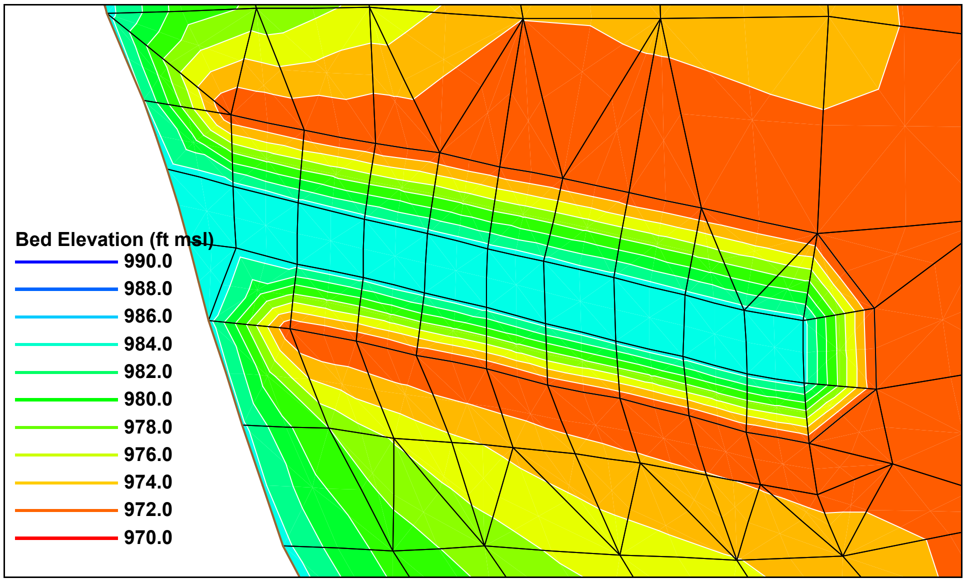

Figure 4. Basic dike in Boyer Bend mesh

Steady state mesh calibration

The Hamburg Bend model was calibrated to a set of water surface profiles developed with HEC-RAS in the Omaha District. Figure 5 shows the HEC-RAS water surface profiles and the RMA2 WES water surface profiles created for the matching reach of river. The 28,000 cfs flow was used as the lowest flow to adequately model a flow rate at which acres of shallow water habitat would be measured.

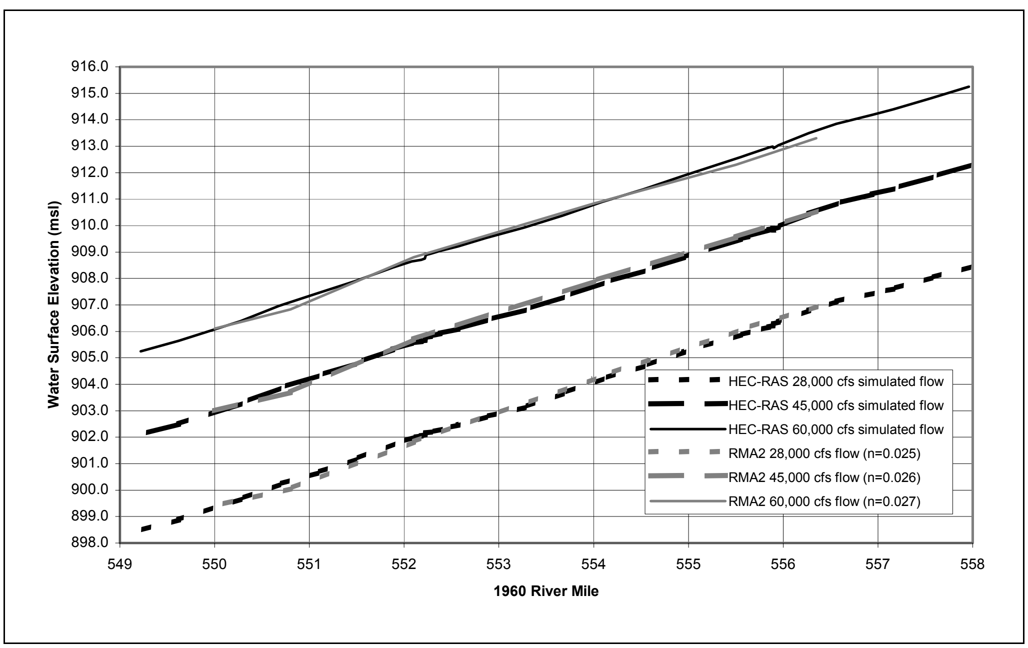

Figure 5. Hamburg Bend model water surface elevation calibration

The Hamburg Bend model includes an off-channel chute designed by USACE-Omaha and implemented in 1995. To better match the existing conditions, the Hamburg Bend model was also calibrated to match the flow split between the main channel of the Missouri and the chute based on field measurements and the HEC-RAS model. Figure 6 plots the RMA2 WES results in reference to measured and RAS modeled splits.

Boundary conditions controls

Initial model runs were made from a cold start and revised to the correct water surface elevation using revision cards. With the addition of multiple revision cards, the run time for the 11,000 element mesh began to exceed 30 minutes. Hot start files were implemented to reduce run time. Unfortunately, the stable solutions from the cold start solutions did not remain stable when run with the hot start file. Only one of the steady state flows stayed stable using the hot start file, while the other two continue to be run from a cold start.

Peclet control of eddy viscosity (EV) is being used at the two higher flow rates. A stable solution using Peclet control was not found at the 28,000 cfs flow. This instability results in the flow continuing to be run with manually specified EV controls. EV and Peclet values were minimized until instability was observed in the model solution. Such effects included undirected rotation of velocity magnitudes in the channel and loss of eddy formation. Figure 7 shows the velocity magnitude of water passing over a dike at 60,000 cfs. Figures 8 and 9 show the change in flow regime and the flow rate drops to 45,000 cfs and 28,000 cfs, respectively.

The computed change in water velocity and direction with varying flow rate will be used as a tool to help determine the general flow rate ranges at which formation of shallow water areas occur. Identifying changing flow dynamics will ideally allow for the design of structures that create and support shallow water habitat across a wide range of river flow rates.

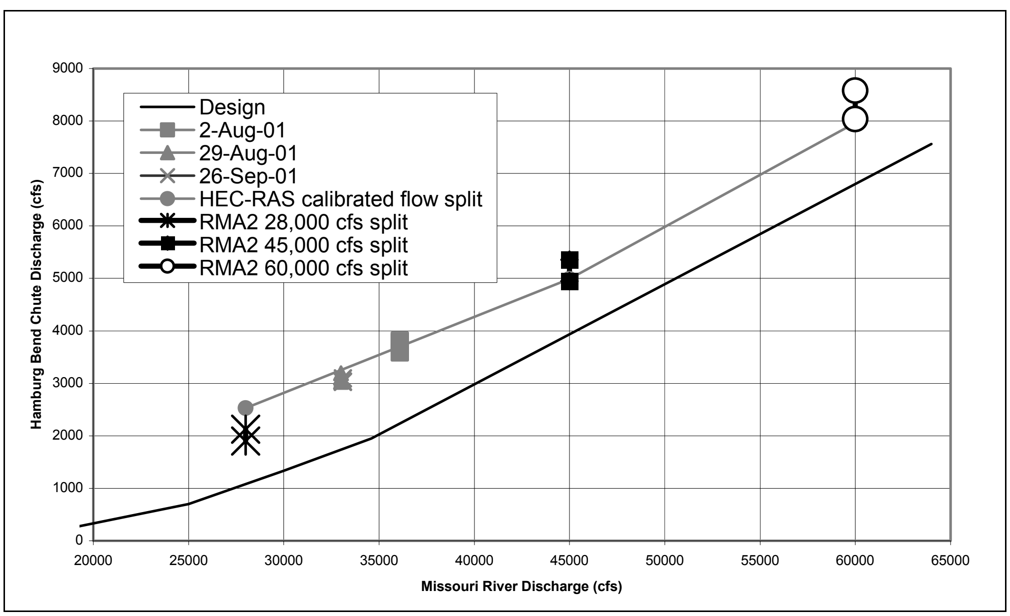

Figure 6. Hamburg Bend chute flow rate splits

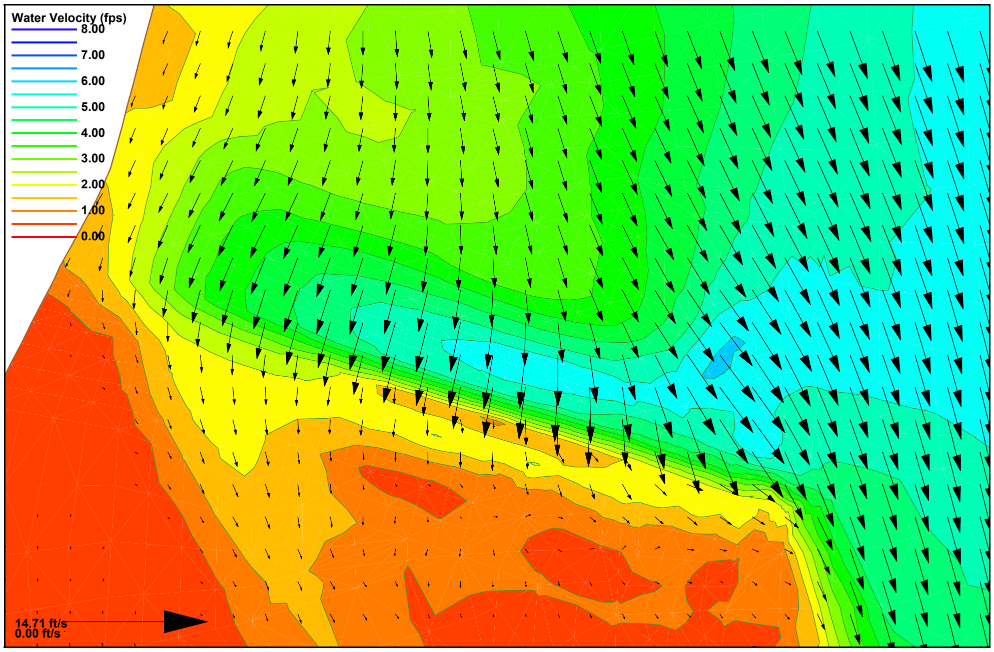

Figure 7. Flow velocities over dike top at 60,000 cfs – 1.6 ft water depth over dike

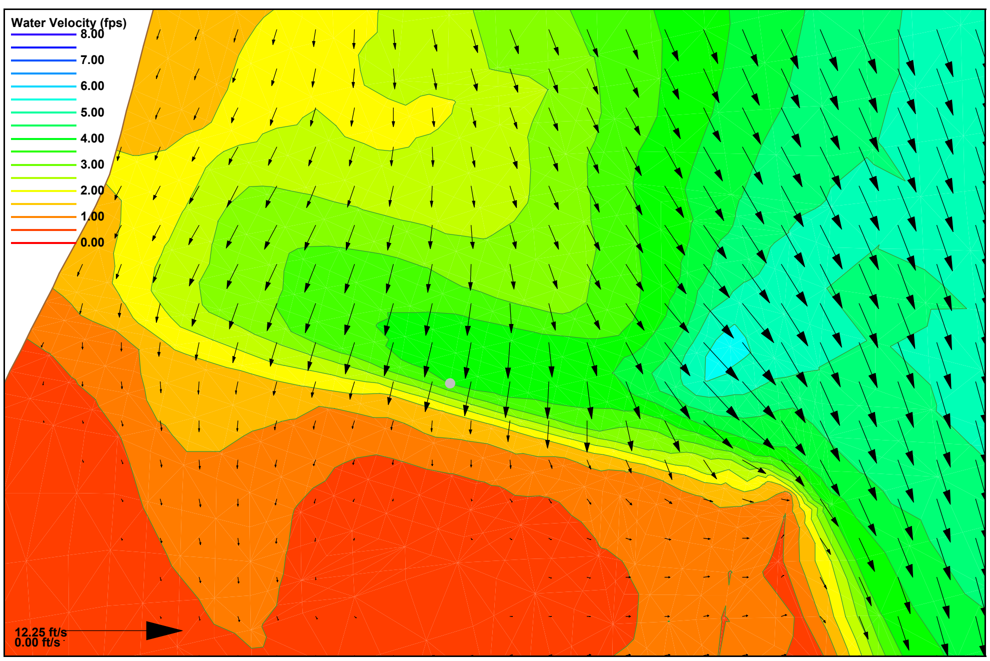

Figure 8. Flow velocities over dike top at 45,000 cfs – 1.35 ft of dike exposed
(Note: due to the use of marsh porosity, model output shows water velocity over dikes that does not actually exists)

The marsh porosity function is being used at all flow rates to reduce wetting and drying problems. This function retains a thin layer of water on all elements, regardless of actual water coverage. This is not a significant concern with steady state model runs, but will be an important factor with unsteady flows. In addition, a comparison of stable solutions at the three flowrates with and without the vorticity function yielded only a slight difference in water velocity magnitude at one dike structure in the mesh. Based on recommendations from Engineer Research

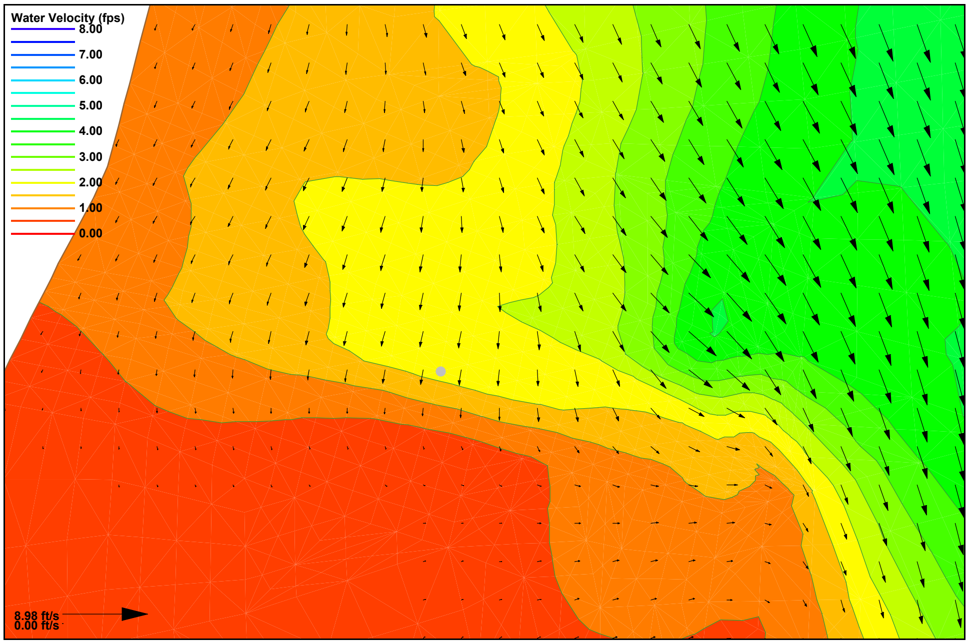

Figure 9. Flow velocities over dike top at 28,000 cfs – 4.7 ft of dike exposed
(Note: due to the use of marsh porosity, model output shows water velocity over dikes that does not actually exists)

Development Center (ERDC, Vicksburg, MS), the vorticity function will be retained in the model.

The current Hamburg Bend model mesh has been through numerous revisions and extensive sensitivity analysis with model controls including EV, Peclet control of EV, elemental drying and marsh porosity, Manning's n roughness for multiple material types, roughness by depth, and vorticity. The Hamburg Bend model mesh has been calibrated to multiple steady state flow rates as shown in Figure 5. In addition to these calibrations, measured velocity data will be collected with an acoustic Doppler current profiler in the summer of 2003. The mesh will be verified with these measurements when available.

Successive steps from the current status include addition of sediment with SED2D WES to evaluate changes in bed elevation due to erosion and deposition of sediments. Upon inclusion of sediment, an unsteady flow model for a 24-hour time duration will be developed, and eventually a model for a complete navigation season on the Missouri River (April 1 – November 30) will be developed.

Based on successful creation of a model to simulate an entire season, modification of the mesh will allow for analysis to multiple design alternatives, all with the goal of increasing shallow water habitat along the river corridor.

There are few limitations with the finished models on what alternatives can be explored. Initial evaluations will include:

1. Shallow notches in dike tops near or behind the current channel bank,
2. Developing a wider range of dike top elevations along the channel,
3. Adding new structures, possibly dikes and chevrons, and
4. Adjusting alignment and angle at which structures intercept flow.

These alternatives, as well as any new concepts developed, will be investigated while emphasizing the maximization of habitat development with minimal impact on the navigation channel.

Conclusions

The two-dimensional models developed on the main stem of the Missouri River in support of the Missouri River Bank Stabilization and Navigation, Fish and Wildlife Mitigation Project are currently being used to evaluate modifications to the in-channel dikes for creation of shallow water habitat. Through design, refinement, and basic calibration, computed results with the two-dimensional Hamburg Bend model have reproduced measured water surface elevations and flow splits at the project site.

The Boyer Bend model is being developed with lessons learned in the refinement of the Hamburg Bend model, including maximizing quadrilateral elements and refined parameters for the boundary conditions file.

Analysis with these models should allow engineers and designers with USACE Omaha District to better predict the impacts of design changes on Missouri River dikes than was possible in the past.

References

Davinroy, Robert D. et al., September 1999. Sedimentation Study of the Missouri River, Copeland Bend Miles 569 to 564.5; Hydraulic Micro Model Investigation. Technical Report M10. USACE, St. Louis District.

Donnell, B. ed. (1997) Users Guide to RMA2 WES Version 4.3. US Army Corps of Engineers Waterways Experimentation Station Research Laboratory, Vicksburg, MS.

Donnell, B. ed. (2000) Users Guide to SED2D WES Version 4.5. US Army Corps of Engineers Waterways Experimentation Station Research Laboratory, Vicksburg, MS.

Spasojevic, Miodrag, Muste, M, and Holly, F.M., October 2001. Three Dimensional Modeling of the Missouri River at Leavenworth Bend, Analysis of Missouri River Habitat Restoration Measures Using Numerical Modeling. Report No. 296, University of Iowa.

U.S. Army Corps of Engineers, September 1995. Missouri River Navigation Flexibility Study. USACE, Omaha District.

U.S. Army Corps of Engineers, February 2002. Missouri River Streambank Stabilization and Navigation Project Action Plan for Creating 2000 Acres of Shallow Water Habitat by 2005 (Draft). USACE, Omaha District.

U.S. Fish and Wildlife Service, November 2000. U.S. Fish and Wildlife Service Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System. U.S. Fish and Wildlife Service.